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PILOT-SCALE STUDY ON BATAC JIG WASHING OF KIPP MINE COAL - PETRO-CANADA

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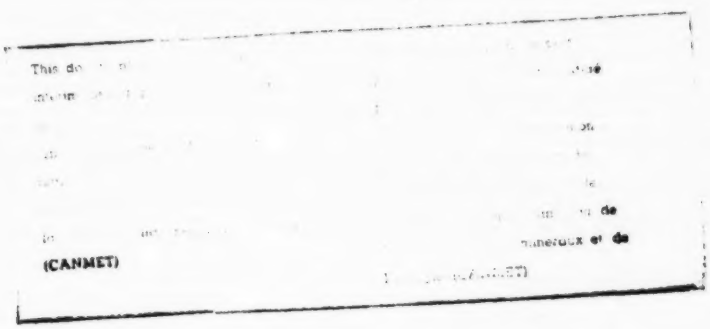

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by

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ABSTRACT

A 18.3 tonne sample of thermal coal from Kipp mine was submitted by Petro-Canada for pilot plant Batac jig evaluation. The objectives of the program were to produce clean coal with a minimum of 24423 kJ/kg (10,500 BTU/lb) heat value and outline a flowsheet to achieve it or higher heat value up to 27,400 kJ/kg (12% ash).

Pilot plant tests included Batac jig circuit with recirculating middlings for the 12.7 x 0.6 mm size fraction, two stage water-only-cyclone for the 0.6x0.15 mm fraction and froth flotation for the minus 0.15 mm. Results indicate a recovery of 68.6 per cent by mass at 12.76 per cent ash (equivalent to 27120 kJ/kg) with 84.56 per cent thermal recovery.

Based on coal characteristics and pilot plant testing, a flowsheet is proposed to gravimetrically clean the 100 x 12.7, 12.7 x 0.5 and 0.5 x 0.15 mm in heavy medium bath, heavy medium cyclone, and water-only-cyclone respectively. The minus 0.15 mm is upgraded in a bank of froth flotation cells. The Batac jig was considered for the 12.7 x 0.5 mm fraction, however, due to significant amounts of near density material between 1.6 and 1.8 relative densities, the heavy medium cyclone showed 2-3 per cent higher thermal recovery than the projected jig performance. The estimated overall thermal recovery is expected to be approximately 92 per cent at 12-13 per cent ash in the clean coal.

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ÉTUDE À L'ÉCHELLE PILOTE SUR LE LAVAGE DU CHARBON DE LA MINE KIPP DANS UN BAC À PISTONNAGE BATAC -- PETRO-CANADA

par

M.W. Mikhail*, I.S. Parsons** et O.E. Humeniuk***

RÉSUMÉ

Un échantillon de charbon thermique de 18,3 tonnes de la mine Kipp a été soumis à Petro-Canada à des fins d'évaluation dans un bac à pistonnage Batac à l'échelle pilote. Ce programme avait pour but de produire un charbon épuré ayant un pouvoir calorifique minimal de 24 423 kJ/kg (10 500 BTU/lb) et de présenter un schéma de traitement pour réaliser cet objectif ou atteindre un pouvoir thermique allant jusqu'à 27 400 kJ/kg (12 % de cendres).

Les essais à l'échelle pilote comprenaient un circuit à pistonnage Batac avec des mixtes de recirculation pour la fraction granulométrique de 12,7 x 0,6 mm, un hydrocyclone à deux étapes pour la fraction de 0,6 x 0,15 mm et la flottation par mousse pour celle inférieure à 0,15 mm. Les résultats ont donné un pourcentage massique de 68,6 % à 12,76 % de cendres (équivalant à 27 120 kJ/kg) avec une récupération thermique de 84,56 %.

Selon les propriétés du charbon et les essais à l'échelle pilote, on propose un schéma afin de laver par gravimétrie les fractions de 100 x 12,7, 12,7 x 0,5 et 0,5 x 0,15 mm, respectivement dans un bac de séparation à milieu dense, un cyclone à milieu dense et un hydrocyclone. La fraction inférieure à moins 0,15 mm est améliorée dans une banque de cellules de flottation. Le bac à pistonnage a été considéré pour la fraction de 12,7 x 0,5 mm, mais en raison des quantités importantes de produit de densité voisine de la coupure ayant une densité relative entre 1,6 et 1,8, le cyclone à milieu dense a présenté une récupération thermique supérieure de 2 à 3 % à la performance prévue du bac à pistonnage. On prévoit que la récupération thermique globale atteindra environ 92 % à 12-13 % de cendres dans le charbon épuré.

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INTRODUCTION

A pilot plant scale Batac jig was recently installed at the Coal Research Laboratory (CRL) pilot plant facilities in Edmonton. The Batac jig project is partly financed by several coal companies to evaluate the Batac jig in washing their coals. The project is intended to generate test data and experience on Canadian coals, to reduce risks in designing new plants and in modifying existing ones.

In Germany, use of the Batac jig in washing both coarse and fine fractions is common in newly designed plants and is gradually replacing the heavy medium bath in existing plants. The common practice is to use jigs to wash the coarse (plus 10 mm) and fine (10 x 0.5 mm) fractions separately. The increased application of the Batac jig in Germany and other countries is claimed to be due to the following claimed advantages (1):

1. Large tonnages can be treated, simplify plant layout and size and reduce capital cost
2. Because of its precise controls, the jig is able to respond quickly to changes either in feed rate or in coal characteristics
3. Estimated operating cost is 40% less than for the heavy medium systems
4. Performance compares favourably with heavy medium systems for cutpoints above 1.55 for coals with a limited amounts of near density material.

Generally, Canadian coals are not easy to wash as German coals. The Batac jig offers certain advantages, but an understanding of how it behaves with Canadian coals is not clear. The testing program on different Canadian coals can benefit industry by verifying reported claims and generate data for commercial plant design.

A bulk sample weighing 18.3 tonnes was received from Kipp Mine. The sample was composed of a 4 (Galt): 1 (Whole) blend from two seams. This report represents results and discussions of pilot plant washing tests, evaluates and compares the Batac jig performance with other systems, and determines the feasibility of washing the above mentioned blend from Kipp Mine to meet required objectives.

COAL CHARACTERISTICS

Based on the analysis in Table 1 and according to the ASTM system of classification, the composite sample (blend from Galt and whole seams) can be ranked in the bituminous C category. The analysis given in Table 1 is a split of the bulk sample (approx. 18 tonnes and considered to represent the bulk sample received for washing tests).

SIZE DISTRIBUTION

The sample received is similar to most Foothills high volatile coals, with 13.16 per cent by mass of minus 0.6 mm size. Tables 2 and 3 show the screen analyses of raw coal before and after being crushed to minus 12.7 mm respectively. No significant change in ash for different size ranges is observed as a result of crushing. The amounts of sodium and potasium in the minus 0.044 mm (Table 2) are about two to three times as high as in other size ranges. No significant change in sulphur content is observed with change in particle size.

HEAT VALUE

Thermal content can be reliably expressed as a linear function of the ash content of a given coal. The ash and thermal contents of different densities and size fractions were used to establish the following relationship (Appendix A).

$$kJ/kg\ (db) = 31649 - 354.9 * Ash$$

where ash is expressed in per cent.

A minimum heat value of 24423 kJ/kg (10500 Btu/lb) is required for the clean coal product. This corresponds to 20.36% ash (db) and equivalent to 18.87% ash as received basis (7.3% moisture a.r.b.). Washed coal from a plant will have a moisture content of about 14.5% (mechanically dried) and 12.5% (thermally dried).

WASHABILITY

Washability analyses were carried on two fractions with top size ranges of: 50 mm and 12.7 mm. The coarse size washabilities (minus 50 mm) would more or less represent the raw coal that might be washed in a commercial size plant. The minus 12.7 mm washabilities represent the raw coal being fed to the pilot plant.

Washability curves of the 50 x 0.6 mm in Fig. 1 (data in Table 4) indicate a good theoretical recovery of 76% mass with 12% ash at 1.69 cutpoint (dp). However, at ash levels lower than 12%, a considerable reduction in recovery can be expected.

For the 0.6 x 0.15 mm fraction, washability data (Table 5 and Fig. 2) indicate slightly improved recovery of 80% by mass with 12% ash level at 1.98 dp. Washability curves of the 12.7x0.6 mm (after reducing the top size from 50 to 12.7 mm) indicate slight improvement in coal washability that reflects an increased recovery from 76% (for the 50 x 0.6 mm) to 79% by mass (Table 6 and Fig. 3). No significant change in washability of the 0.6 x 0.15 mm (Table 7 and Fig. 4) is observed.

The overall effect of crushing the ROM from a top size of 100 mm to 50 mm then to 12.7 mm is examined. Figure 5 indicates some improvement in coal washability for dp less than 1.6 as a result of crushing to minus 12.7 mm. However, at the required ash level of 12%, only a slight improvement in recovery was achieved by size reduction, from 76% for 50 x 0.6 mm to 78% by mass 12.7 x 0.6 mm. An improvement of 2% in theoretical recovery may not justify reduction in top size below 50 mm. Also no improvement in washability is observed by crushing from 100 mm to 50 mm top size. As a result, it would be beneficial to wash the coal as coarse as possible to achieve sharper separation at lower cost of preparation.

COAL FRIABILITY

Estimation of the coal friability is essential at an early stage of development for preparation plant design, dust control and handling of coal. Several direct and indirect methods are available to predict coal degradation. The Australian wet attrition test is used to predict the amount of degradation (2). The test treats raw coal on a laboratory scale under conditions simulating commercial wash plant treatment. A 50 kg sample of raw coal is tumbled with 150 kg of water along with a standard number of 50 mm steel cubes in a steel drum of 200 L capacity at 20 rpm. Tumbling duration is 45 s and dependent on raw coal Hardgrove Grindability Index (HGI=49) (2). Size distributions before and after the attrition test are compared to determine the degree of degradation. Also the ΔP index measurement is used to predict the amount of minus 0.6 mm in the future run-or-mine. The ΔP

index value measured on the raw coal sample is 14.5. Figure 6 shows size distribution before and after attrition of the 50 mm x 0 size.

PERFORMANCE PREDICTION

In practice, recoveries would be lower than the theoretical recoveries because of errors of separation inherent in any process. The effect of these errors of separation can be seen from the predicted washing results in Fig. 7 for the plus 0.6 mm fraction (Fig. 7 includes actual pilot plant results which are discussed later). These predictions cover the dp range of 1.45 to 1.80 relative densities. The probable error (r) is a parameter used in prediction calculations to convert the theoretical results (from washability curves) into the practical results which one could expect from the actual process. The prediction curves are for heavy medium cyclone (HMC) and Baum jig. These predictions are necessary to determine pilot plant flowsheet and setting of equipment parameters to achieve the cleaning objectives. From the curves, it is likely that in practice a washed coal with 12% ash (27390 kJ/kg) would be obtained with a calculated thermal recovery (from raw and clean coals thermal values and yields) of 96.4 and 94.3 per cent in kJ for HMC and Baum jig with corresponding dp of 1.72 and 1.64 respectively.

WASHING TESTS

The processing of the Kipp Mine coal sample at the Fuel Processing Laboratory pilot plant facilities included feed preparation, two cleaning circuits, dewatering and water treatment. A detailed description of the 10 tonne/hr. pilot plant facility has been reported earlier (3) and a simplified flowsheet is shown in figure 8. The following is a brief outline of the pilot plant circuits.

Feed Preparation: The raw coal is prepared to a 12.7 mm top size by screening out the -10 mm coal and recombining it with +10 mm fraction which has been crushed in a hammer mill.

Cleaning: a) Coarse coal circuit: The bulk raw coal slurry 12.7 mm X 0 has the minus 0.5 mm fraction removed before processing in a Batac jig. The Batac jig produces a reject product, a middlings (which is recirculated) and a coarse clean coal product.

b) Fine coal circuit: The -0.5 mm fraction which was removed before coarse coal cleaning is processed in a two stage 200 mm diameter water only cyclone. After screening, the -0.15 mm fraction is processed in a bank of 6 Denver flotation cells.

Dewatering: The coarse and fine clean coal fractions are combined and dewatered together in a pusher-type centrifuge. The thickener underflow or fine reject is dewatered in a solid bowl centrifuge while the coarse reject over a 0.6 mm vibrating screen.

Water treatment: Process water containing flotation tailings and secondary compound water cyclone underflow is treated in a bottom fed thickener to produce clarified water for recirculation. The thickened fine reject is then dewatered in a solid bowl centrifuge.

TEST PROCEDURE

The objective of the pilot plant washing tests was to evaluate the performance of the Batac jig in cleaning smalls (12.7 x 0.6 mm) to determine size degradation during washing and to produce clean coal with approximately 12% ash (~ 27400 kJ/kg -db). Optimum thermal recovery was the main criterion in setting the separation cutpoints of both the smalls and fines (minus 0.6 mm) cleaning circuits. A total of seven tests were run with some changes in dp settings. Froth flotation was included in the fines circuit to improve recovery of minus 0.15 mm fine coal. The new cutpoint adjustment system for the Batac jig was tested and evaluated by comparing the set dp and actual dp from error curves.

After the initial adjustment of the Batac jig, cyclones settings and bench scale flotation tests to determine type and amounts of reagents, a short preliminary run was made and samples collected for analysis to determine if further adjustment of the equipment was required. Incremental samples were taken of the raw coal, clean coal and reject products for all tests. The end products of the long runs and some of the intermediate

products were collected to evaluate the overall performance of the plant and determine material balance.

The ash and moisture contents of samples were determined following each test run. Screen and float-sink analyses of the samples of the main runs were carried out by the Birtley Engineering Laboratory in Calgary along with attrition tests.

DISCUSSION OF RESULTS

A total of 16.84 tonne of raw coal with 26.91% ash was washed in the pilot plant and producing a clean coal yield of 68.60% with 12.76% ash (Table 9). Average thermal recovery was 84.56%, however tests 9 and 11 indicate relatively low thermal recoveries of 73.9 and 77.58% respectively. Recovery of coal slimes by froth flotation helped in improving the overall recovery of clean coal (Fig. 8).

PLANT PERFORMANCE

Plant performance is defined by the probable error (r) which reflects the sharpness of separation at a given cutpoint (dp). These parameters are derived from the distribution curve. The distribution curve is a plot of the percentage of the feed to a washing unit that reports as refuse versus the relative density. The cutpoint (dp) is defined as the relative density at which 50% of the feed reports to refuse and 50% to product. The probable error (r) for a distribution curve is one half the difference of the relative density interval at the ordinates of 25 and 75 per cent and this is a measure of the slope of the middle portion of the distribution curve. The better the separation, the steeper the slope of this curve and the smaller the probable error.

Batac Jig Performance

Table 10 shows the summary of three Batac jig tests performance for dp between 1.48 and 1.56. Error curves related to the two size ranges 12.7 x 2 mm and 2 x 0.6 mm fractions are shown in Fig. 9 and combined in Fig. 10. As can be expected dp and r increased with decrease in size, 0.09 and 1.46 (r,dp) for the 12.7 x 2 mm fraction to 0.21 and 1.88 for the 2 x 0.6 mm

fractions respectively. The average r from the three tests is 0.13 corresponding to 1.54 average dp (Table 10). Fluctuation in the water feed rate to the Batac jig during testing might have caused some deterioration in the separation efficiency for tests 6 and 10. Batac jig results are compared with predicted performance from a Baum jig model (Fig. 7). The Batac jig results are poorer than can be expected. Presence of fine flat particles of high ash and fluctuation in upward flow of water might have caused misplacement of high ash particles with the clean coal product and resulted in higher ash clean coal than expected.

The new system for setting the Batac Jig dp is tested and compared with the dp determined from error curves. The system includes a ring of relative density equal to the dp that would float between the reject and clean coal beds and a change in height below or above the set height would trigger the opening or closing of the reject or middling gate. Table 10 data indicate that the ring relative density is comparable to the measured relative density of separation for the 12.7 x 0.6 mm. However, for the 12.7 x 2mm fraction, the actual dp's are lower than the rings relative densities while for the 2 x 0.6 mm the actual dp,s are much higher than the rings relative densities. This is possibly caused by relatively high upward flow of water and presence of fine flat particles (high in ash) which influence fine particles more than coarse ones.

Water-only-Cyclone Performance

The two stage water-only-cyclones (WOC) are set to separate at a relatively high dp (Table 11). The two stage cyclones produced good reject in Tests 4 to 8 with 58.5 to 65.7% ash (r=0.31 at 1.88 dp Table 12). Tests 9 and 10 with high vortex finder clearance produced low ash reject but no significant improvement (reduction) in clean coal ash (Table 11). Froth flotation is used to minimize losses of fine coal in the 0.15 mm x 0 fraction to fine reject.

Froth Flotation Performance

Bench scale froth flotation tests confirmed the low yields reported by Birtley Engineering tests. However, pilot plant flotation results (Table 13) with the same reagents at higher dosages gave significantly higher yields. Froth concentrate ash ranged between 15 and 20 per cent with

equivalent contents of 53 to 59 per cent ash for the tailings. Reagent consumption was high (5-6Kg/tonne). The low intensity of agitation and possibly less aeration in the pilot plant cells in comparison with the bench flotation cell might have been the cause of improved selectivity in cleaning of raw coal slimes (0.15 mm x 0).

SIZE DEGRADATION

Changes in screening characteristics resulting from degradation during washing can be evaluated by comparing the analyses of raw coal and reconstituded feed. The reconstituted feed is obtained by combining the individual product size analyses, weighted according to their respective mass yields.

The screen analysis of reconstituted feed as compared with raw feed analysis of Test 10 (Table 14) and raw feed head sample compared with wet attrition test (Australian attrition test), Fig. 11 indicated some change in size consist. Degradation during the pilot plant washing test increased the amount of minus 0.6 mm (Table 14) from 9.54 per cent to 14.46 per cent by mass (for 12.7 mm x 0). The wet attrition test (carried on a sample different in size consist than Test 10) shows 23.5 per cent by mass as compared with 18.5 per cent of minus 0.6 mm before attrition (Fig. 11). The amount of degradation during washing and wet attrition test are comparable (about 5 per cent increase in minus 0.6 mm) on two different samples.

The predicted amount of minus 0.6 mm in the run-of-mine (ROM) from ΔP index measurement is 24.8 per cent by mass, as calculated from the following equation (4):

$$\text{Mass \% of minus 0.6mm in ROM} = 14.90 + 0.68\,\Delta P$$

PROPOSED FLOWSHEET

Two options are considered in preparing the raw coal: crushing either to 100 mm or to 50 mm top size. Both options are evaluated by performance prediction of thermal recovery at 12 to 13 per cent ash in clean coal (Fig. 12 to 16).

a) 100 mm top size (washabilities in Appendix A): The flowsheet would include heavy medium bath (HMB) for the 100 x 12.7 mm fraction, heavy medium cyclone (HMC) or jig for the 12.7 x 0.5 mm and WOC for the 0.5 x 0.15 mm. Performance predictions for the HMB at 27400 kJ/kg

(≈12% ash) indicate 87.5 per cent thermal recovery (Fig. 12). Fig. 13 shows performance predictions for HMC and Baum jig models for the 12.7 x 0.5 mm fraction. Due to coal washability characteristics, jigs performance is approximately 2-3 per cent lower in thermal recovery than HMC for dp between 1.5 and 1.9. For HMC, the predicted thermal recovery at 27400 kJ/kg (≈12% ash) is 95.5 per cent. WOC at 25750 kJ/kg (≈16% ash) indicated 88 per cent thermal recovery (Fig. 14). The overall weighted thermal recovery for HMB, HMC and WOC is equivalent to 92.4 per cent for clean coal ash between 12 and 13 per cent.

b) 50 mm top size: The flowsheet would include HMC or jig for 50 x 0.6 mm (only because size analysis was performed on 0.6 mm screen size instead of 0.5 mm) and WOC for 0.6 x 0.15 mm. Performance predictions for HMC and the Baum jig (Fig. 15) indicate that at 27400 kJ/kg, the HMC would give 92 per cent thermal recovery which is approximately 3 per cent higher than would be obtained with the Baum jig. The WOC indicates lower ash than in option (a) at 1.9 dp (13.4%) with 88.5 per cent thermal recovery (Fig. 16). The overall weighted thermal recovery for HMC and WOC is 91.6 per cent at approximately the same ash level in clean coal as in option (a).

The above comparison indicates no advantage in thermal recovery by crushing the coal finer than 100 mm top size. The suggested schematic flowsheet in Fig. 17 would be expected to produce clean coal with 12-13 per cent ash which is equivalent to 27400-27000 kJ/kg. The HMC flowsheet includes HMB for the plus 12.5 mm, HMC for the 12.5 x 0.5 mm, WOC for 0.5 x 0.15 mm and froth flotation for the minus 0.15 mm. Pilot plant results for WOC and froth flotation project relatively high ash clean coal ranging between 15 to 20 per cent ash. Based on the schematic flowsheet (Fig. 17) and Fig. 12,13 and 14 and Table 13 the overall thermal recovery is expected to be approximately 92 per cent at 12-13 per cent ash in clean coal.

CONCLUSIONS AND RECOMENDATIONS

1. No significant improvement in coal washability would be achieved by crushing the raw coal from 100 mm to 50 mm and 12.7 mm top sizes. For the 50 mm top size, the 12 per cent ash level can be theoretically achieved at 1.69 dp for the 50 x 0.6 mm fraction and 1.98 dp for the 0.6 x 0.15 mm fraction respectively.
2. Both pilot plant testing and wet attrition tests indicate an increase of about 5 per cent by mass in the amount of minus 0.6 mm fraction as a result of degradation: The amount of minus 0.6 mm predicted for future run-of-mine raw coal is 24.8 per cent by mass as calculated from ΔP index measurement.
3. Batac jig testing for the 12.7x0.6 mm shows poorer performance than predictions based on Baum jig performance. The Batac jig performance is acceptable for the 12.7 x 2 mm fractions, however high dp and probable error are indicated for the 2 x 0.6 mm fraction. Presence of fine flat particles with high ash and fluctuation in upward flow of water might have caused misplacement of high ash particles with the clean coal product and resulted in higher ash clean coal than can be expected. Pilot plant tests indicate an average thermal recovery of 84.6 per cent at 12.8 per cent ash in clean coal. Pilot plant froth flotation performance was better than indicated by results of bench scale tests. Froth ash ranged between 15 and 20 per cent in the plant with corresponding tailings ashes of 53 and 59 per cent. However, much higher dossages of reagents were required.
4. Based on coal characteristics and pilot plant testing an outline of a flowsheet is proposed, which includes two processes for coarse cleaning: a heavy medium bath for the plus 12.7 mm and heavy medium cyclones for 12.7 x 0.5 mm. For fines cleaning, two steps are proposed: Water-only-cyclone for 0.5 x 0.15 mm and froth flotation for minus 0.15 mm. The overall thermal recovery is expected to be approximately 92 per cent at 12-13 per cent ash in clean coal.

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Table 1 - Composite analysis: Petro-Canada bulk shipment.

	As Rec'd	Dry (db)
Moisture (%)	7.30	-
Ash (%)	25.70	27.72
Volatile Matter (%)	29.02	31.31
Fixed Carbon (%)	37.98	40.97
kJ/kg (det.)	21233*	22905*
Sulphur (%)	0.52	0.56
Sulphur (kg/MkJ)	0.245	0.244
Hardgrove Grindability Index	49	
Na (%)	0.084	0.091
K (%)	0.003	0.003

*For plus 44 μm which represents 97.1% of total by mass.

Table 2 - Size consist and other analyses of composite sample (50 mm x 0)

Particle Size mm	Mass%	Ash%	kJ/kg	S%	Na%	K%	Cumulative Mass%	Cumulative Ash%	Cumulative kJ/kg
50.0 - 25.4	11.20	32.43	21025	0.52	0.109	0.004	11.20	32.43	21025
25.4 - 12.7	15.89	27.10	23153	0.56	0.082	0.003	27.09	29.30	22273
12.7 - 6.3	20.10	24.97	23676	0.57	0.088	0.003	47.19	27.46	22871
6.3 - 3.35	12.95	22.60	24267	0.57	0.080	0.002	60.14	26.41	23171
3.35 - 2.0	13.50	26.21	23220	0.54	0.086	0.002	73.64	26.37	23180
2.0 - 0.6	13.20	29.34	22037	0.55	0.108	0.003	86.84	26.83	23007
0.6 - 0.15	8.07	26.07	22641	0.65	0.064	0.002	94.91	26.76	22976
0.15 - 0.074	1.36	28.73	21539	0.70	0.058	0.002	96.27	26.79	22955
0.074 - 0.044	0.73	34.78	19483	0.68	0.047	0.002	97.00	26.85	22929
- 0.044	3.00	56.10	-	0.48	0.177	0.006	100.00	27.73	-
TOTAL	100.00	27.73	22929	0.56	0.091	0.003	-	-	-

Mean Particle size 11.7

Table 3 - Size analysis of raw coal fed to the pilot plant (12.7 mm x 0)

Particle Size mm	Mass %	Ash %	kJ/kg	Cumulative Mass %	Cumulative Ash %	Cumulative kJ/kg
+ 12.7	0	0	0	0	0	0
12.7 - 6.3	2.58	29.82	21066	2.58	29.82	21066
6.3 - 3.35	23.89	25.60	22564	26.47	26.01	22418
3.35 - 2.0	28.22	25.35	22652	54.69	25.67	22539
2 - 0.6	26.61	27.09	22035	81.30	26.13	22375
0.6 - 0.15	13.20	25.54	22585	94.50	26.05	22404
0.15 - 0.074	1.37	28.67	21474	95.87	26.09	22390
0.074 - 0.044	0.85	34.29	19474	96.72	26.16	22365
- 0.044	3.28	59.75	10444	100.00	27.26	21974
TOTAL	100.00	27.26	21974	-	-	-

Table 4 - Washing characteristics of Petro-Canada coal 50 x 0.6 mm (86.84% of total)

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.85	4.08	30201	0.85	4.08	30201	100.00	27.14	22017
1.30 - 1.35	41.33	6.59	29310	42.18	6.54	29328	99.15	27.34	21947
1.35 - 1.40	18.08	11.55	27550	60.26	8.04	28795	57.82	42.17	16683
1.40 - 1.45	4.24	17.63	25392	64.50	8.67	28571	39.74	56.10	11739
1.45 - 1.50	2.74	22.61	23625	67.24	9.24	28369	35.50	60.69	10108
1.50 - 1.60	4.24	30.61	20786	71.48	10.51	27919	32.76	63.88	8978
1.60 - 1.80	10.07	49.10	14223	81.55	15.27	26228	28.52	68.83	7222
1.80 - 2.00	4.05	62.35	9521	85.60	17.50	25438	18.45	79.59	3402
2.00 - 2.17	6.01	81.82	2611	91.61	21.72	23940	14.40	84.44	1681
2.17 - Sink	8.39	86.32	1014	100.00	27.14	22017	8.39	86.32	1014

Table 5 - Washing characteristics of Petro-Canada coal 0.6 x 0.15 mm (8.07% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.30	3.71	30332	0.30	3.71	30332	100.00	25.59	22568
1.30 - 1.35	43.64	4.82	29938	43.94	4.81	29941	99.70	25.65	22544
1.35 - 1.40	14.23	8.63	28586	58.17	5.75	29609	56.06	41.87	16789
1.40 - 1.45	5.34	12.26	27298	63.51	6.29	29415	41.83	53.18	12776
1.45 - 1.50	2.80	16.07	25946	66.31	6.71	29268	36.49	59.17	10651
1.50 - 1.60	3.61	23.59	23277	69.92	7.58	28959	33.69	62.75	9379
1.60 - 1.80	4.20	37.69	18273	74.12	9.28	28354	30.08	67.45	7712
1.80 - 2.00	6.09	52.16	13237	80.21	12.54	27198	25.88	72.28	5998
2.00 - 2.17	3.60	63.75	9024	83.81	14.74	26418	19.79	78.47	3800
2.17 - Sink	16.19	81.74	2639	100.00	25.59	22568	16.19	81.74	2639

Table 6 - Washing characteristics of Petro-Canada coal fed to pilot plant 12.7 x 0.6 mm (81.30% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.80	3.48	30414	0.80	3.48	30414	100.00	25.94	22443
1.30 - 1.35	42.72	4.86	29924	43.52	4.83	29933	99.20	26.12	22379
1.35 - 1.40	17.36	11.12	27703	60.88	6.63	29297	56.48	42.20	16672
1.40 - 1.45	4.65	17.06	25594	65.53	7.37	29034	39.12	55.99	11777
1.45 - 1.50	2.61	23.38	23351	68.14	7.98	28817	34.47	61.25	9913
1.50 - 1.60	3.08	30.86	20697	71.22	8.97	28466	31.86	64.35	8812
1.60 - 1.80	9.71	47.89	14653	80.93	13.64	26808	28.78	67.93	7540
1.80 - 2.00	4.88	61.98	9652	85.81	16.39	25833	19.07	78.14	3918
2.00 - 2.17	3.97	79.35	3488	89.78	19.17	24845	14.19	83.69	1947
2.17 - Sink	10.22	85.38	1348	100.00	25.94	22443	10.22	85.38	1348

Table 7 - Washing characteristics of Petro-Canada coal fed to pilot plant 0.6 x 0.15 mm (13.20% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	1.20	3.60	30371	1.20	3.60	30371	100.00	25.04	22764
1.30 - 1.35	41.05	4.94	29896	42.25	4.90	29909	98.80	25.30	22672
1.35 - 1.40	15.76	8.01	28806	58.01	5.75	29610	57.75	39.76	17536
1.40 - 1.45	6.63	12.00	27390	64.64	6.39	29382	41.99	51.68	13307
1.45 - 1.50	3.30	17.23	25534	67.94	6.91	29195	35.36	59.12	10666
1.50 - 1.60	3.10	26.80	22138	71.04	7.78	28887	32.06	63.44	9136
1.60 - 1.80	4.29	40.43	17300	75.33	9.64	28227	28.96	67.36	7744
1.80 - 2.00	6.14	54.53	12296	81.47	13.02	27027	24.67	72.04	6082
2.00 - 2.17	3.38	66.11	8186	84.85	15.14	26276	18.53	77.84	4023
2.17 - Sink	15.15	80.46	3094	100.00	25.04	22764	15.15	80.46	3094

Table 8 - Summary of products analyses - washing tests (ash contents on dry basis).

Test No.	%	Raw Coal	Clean Coal			Final Products		
			Batac Jig	WOC	Froth Flotation	Clean Coal	Coarse Reject	Fine Reject
4	Ash	28.02	15.24	17.14	-	14.39	60.03	51.57
	Moisture*	8.22	-	-	-	14.54	-	32.27
	Yield	100.00	-	-	-	71.40	24.40	4.20
5	Ash	27.09	15.02	13.92	16.21	14.36	54.28	44.88
	Moisture	-	-	-	-	12.16	26.69	19.00
	Yield	100.00	-	-	-	-	-	-
6	Ash	28.28	13.18	17.60	19.00	12.65	62.82	44.23
	Moisture	-	-	-	-	13.81	37.73	23.15
	Yield	100.00	-	-	-	71.41	20.44	8.15
7	Ash	25.71	13.03	17.15	15.01	12.72	60.15	44.03
	Moisture	-	-	-	-	12.67	27.75	22.21
	Yield	100.00	-	-	-	74.30	18.10	7.60
8	Ash	27.82	13.44	19.44	15.38	14.08	60.43	45.63
	Moisture	8.47	-	-	-	13.73	28.71	26.01
	Yield	100.00	-	-	-	69.51	11.27	19.22
9	Ash	27.48	12.43	15.28	19.86(1) 12.83(2)	12.07	55.39	34.38
	Moisture	8.65	-	-	-	12.04	28.00	18.33
	Yield	100.00	-	-	-	59.13	27.07	13.08
10	Ash	27.09	12.03	18.09	20.19	12.49	55.79	55.95
	Moisture	8.25	-	-	-	11.66	22.80	29.67
	Yield	100.00	-	-	-	69.67	22.94	7.39

moisture
(1) Froth cells #1 (four cells)
(2) Froth cells #2 (two cells)

Table 9 - Thermal recovery: washing tests.

Test	Raw Coal		Clean Coal		
	Mass kg	Ash %	Yield %	Ash %	Thermal Recovery %
4	2268	28.02	71.40	14.39	87.31
5	1814	27.09	-	14.36	-
6	1361	28.28	71.41	12.65	89.74
7	2268	25.71	74.30	12.72	89.51
8	1814	27.82	69.51	14.08	85.07
9	1814	27.48	59.13	12.07	73.90
10	3175	27.09	69.67	12.49	86.05
11	2324	24.67	63.91	10.87	77.58
Total	16838	26.91	68.60	12.76	84.56

Table 10 - Summary of Batac jig performance.

Test No.	Jig Set dp	Actual Cutpoint (dp)			Performance					
		12.7 x 2 mm	2 x 0.6 mm	12.7x0.6 mm	12.7 x 2 mm		2 x 0.6 mm		12.7 x0.6 mm	
					r*	ea**	r	ea	r	ea
6	1.56	1.52	2.14	1.56	0.10	69	0.24	103	0.15	93
10	1.54	1.48	1.86	1.57	0.11	82	0.21	101	0.13	-
11	1.54	1.46	1.88	1.48	0.09	59	0.21	119	0.11	84
Average	1.55	1.49	1.96	1.54	0.10	70	0.22	107.6	0.13	88

* Probable error
** Error area

Table 11 - Water-only-cyclone washing results.

Test No.	VFC* of Primary WOC mm		Product		Recon'd Feed (¯+0.15mm)
			Clean Coal	Reject	
4	50	Mass%	84.1	15.9	100.0
		Ash%	17.1	65.7	24.8
5	75	Mass%	75.6	24.4	100.0
		Ash%	13.9	60.9	25.4
6	75	Mass%	83.4	16.6	100.0
		Ash%	17.6	59.7	24.6
7	75	Mass%	-	-	-
		Ash%	17.15	58.5	-
8	75	Mass%	91.2	8.8	100.0
		Ash%	19.4	63.1	23.2
9	140	Mass%	54.1	45.9	100.00
		Ash%	15.3	31.2	22.6
10	100	Mass%	63.3	36.7	100.0
		Ash%	18.1	46.0	28.3

VFC - Vortex finder clearance
**Secondary WOC the VFC was 50 mm for all tests

Table 12 - Summary of Water-only cyclone performance.

Test No.	dp	r	ea
6	1.88	0.31	133
10	1.75	0.24	131
11	1.64	0.25	131
Average	1.76	0.27	132

Table 13 - Pilot plant froth flotation testing results - Petro-Canada.
(Reagents 6:1 (Kerosene: MIBC), ≈3-6 kg/tonne.)

Product	Test 5		Test 6		Test 7		Test 8		Test 10	
	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %
Froth	15.5	16.2	22.1	19.0	25.8	15.0	24.9	15.4	24.2	20.2
Tailings	84.5	53.8	77.9	56.2	74.2	59.5	75.1	58.5	75.8	56.9

Mass is calculated from ash balance with estimated feed ash to froth cells of 48.0%.

Table 14 - Degradation during washing.

Particle Size mm	Raw Coal		Reconstituted after washing		Cumulative			
					Raw Coal		Recon. after washing	
	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %	Mass %	Ash %
+ 12.7	0.60	37.53	0.48	26.25	0.60	37.53	0.48	26.25
12.7 - 6.3	9.12	21.76	6.20	37.53	9.72	22.73	6.68	36.72
6.3 - 3.35	30.56	22.90	21.53	27.40	40.28	22.86	28.21	29.61
3.35 - 2.0	28.35	23.11	28.76	20.64	68.63	22.96	56.97	25.08
2 - 0.6	21.83	21.69	28.57	19.56	90.46	22.66	85.54	23.24
0.6 - 0.15	5.10	27.53	7.68	24.72	95.56	22.92	93.22	23.36
0.15 - 0.074	1.19	34.57	1.77	28.73	96.75	23.06	94.99	23.46
0.074 - 0.044	0.79	38.30	0.83	36.40	97.54	23.18	95.82	23.57
- 0.044	2.46	57.38	4.18	66.61	100.00	24.02	100.00	25.37
TOTAL	100.00	24.02	100.00	25.37	-	-	-	-

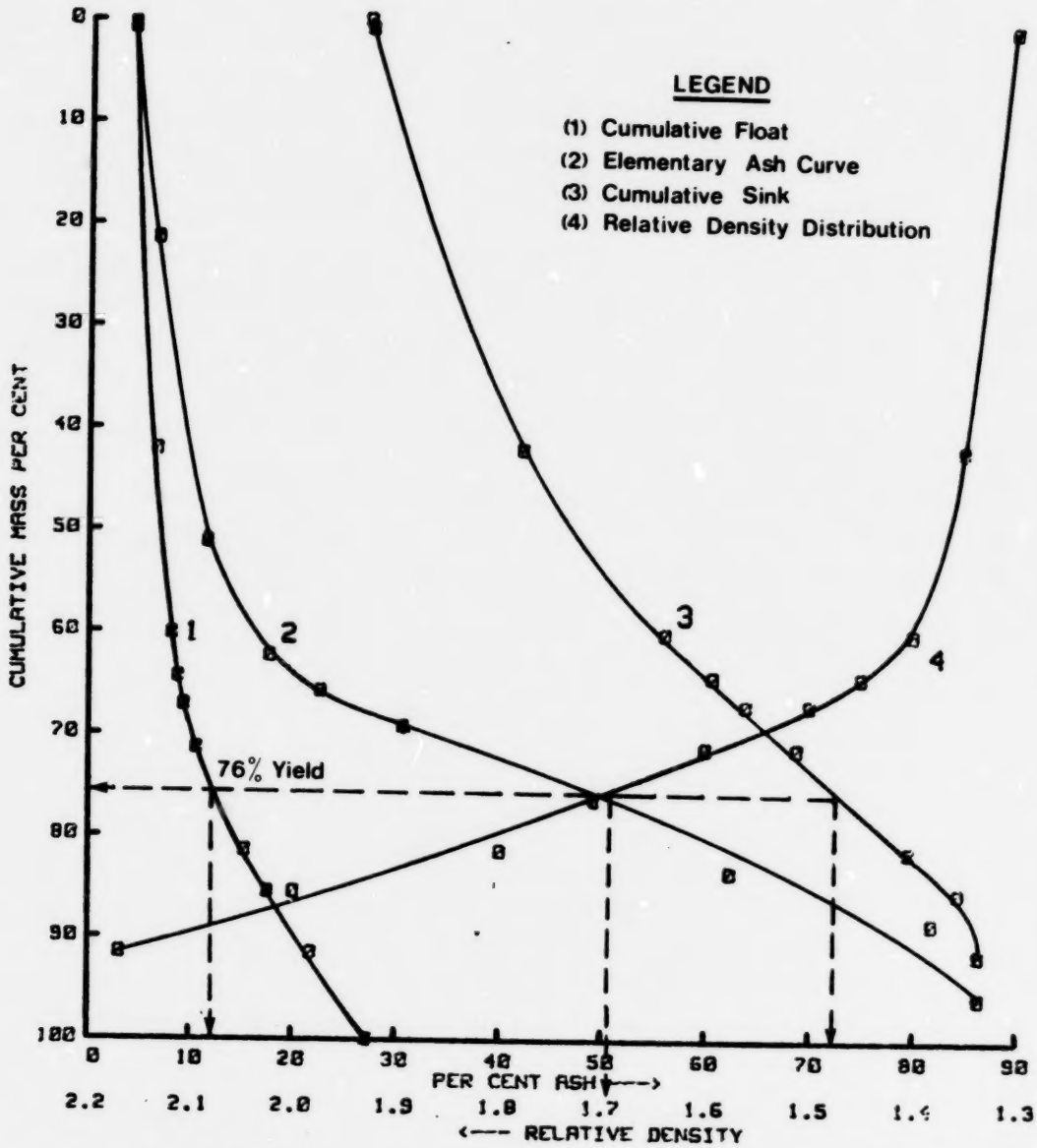


Fig. 1 - Washability curves: Kipp mine coal 50 x 0.6 mm (86.84% of total)

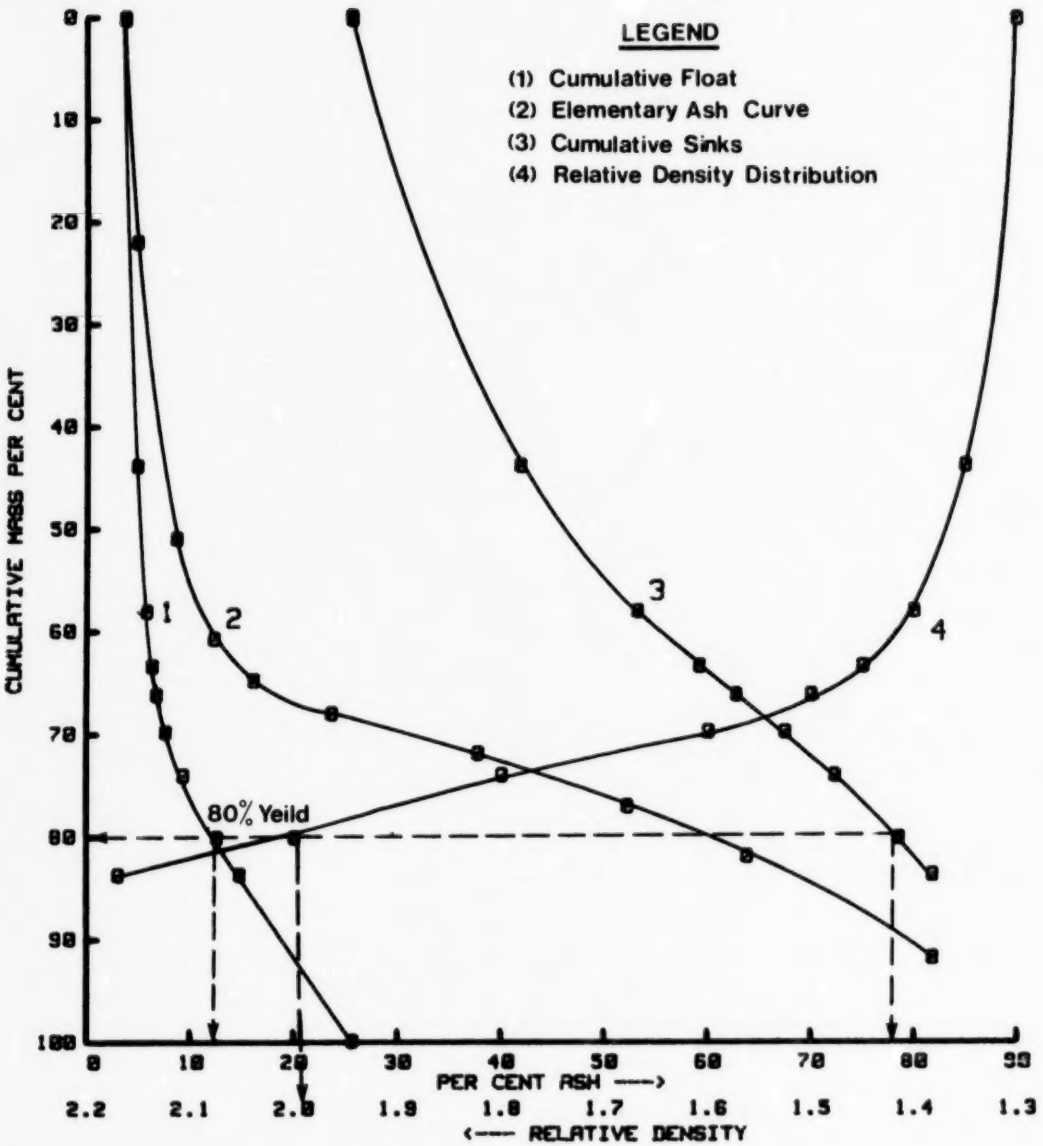


Fig. 2 - Washability curves: Kipp mine coal 0.6 x 0.15 mm (8.07% of total).

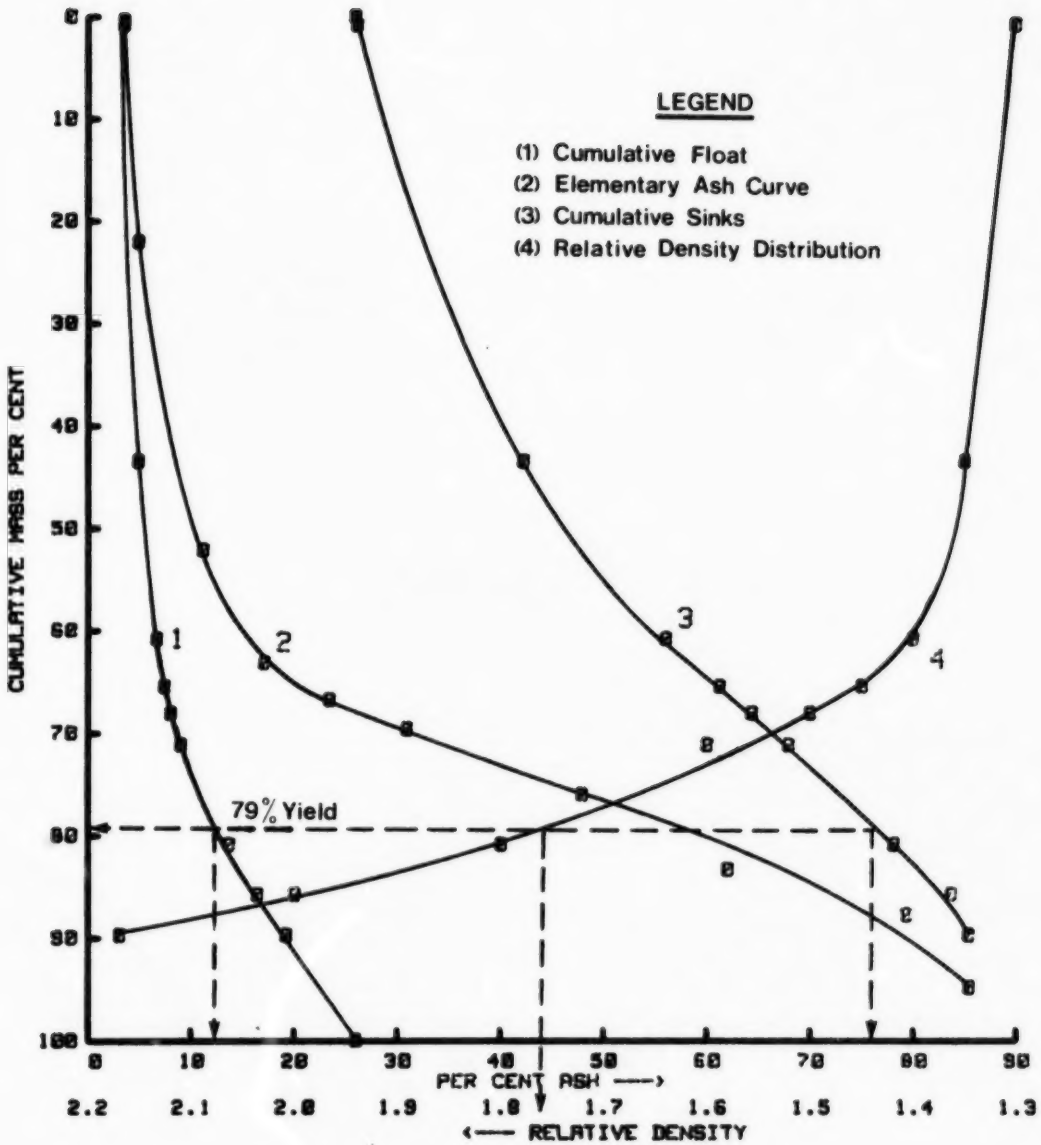


Fig. 3 - Washability curves: Kipp mine coal 12.7 x 0.6 mm (81.30% of total).

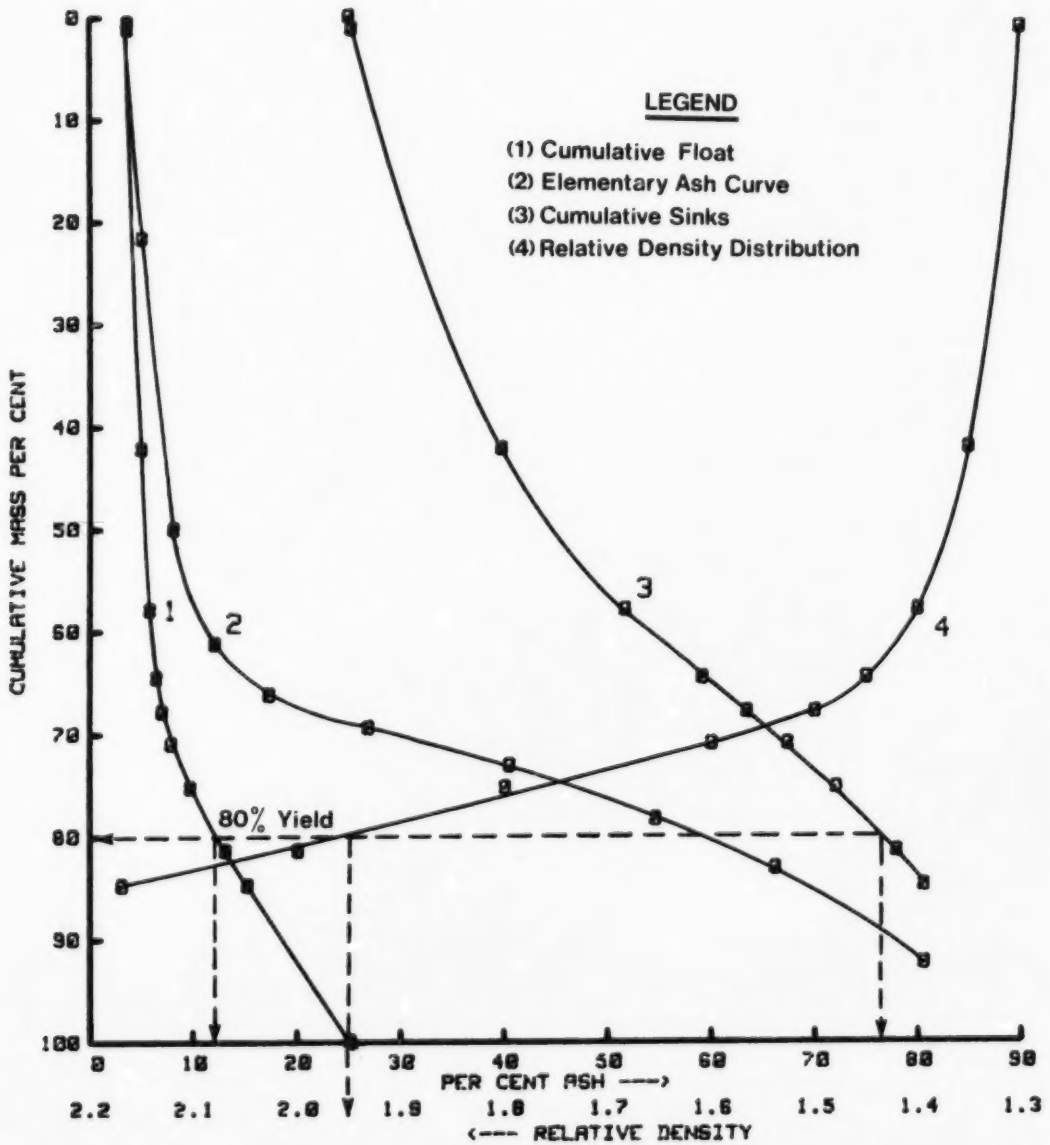


Fig. 4 - Washability curves: Kipp mine coal 0.6 x 0.15 mm (13.20% of total).

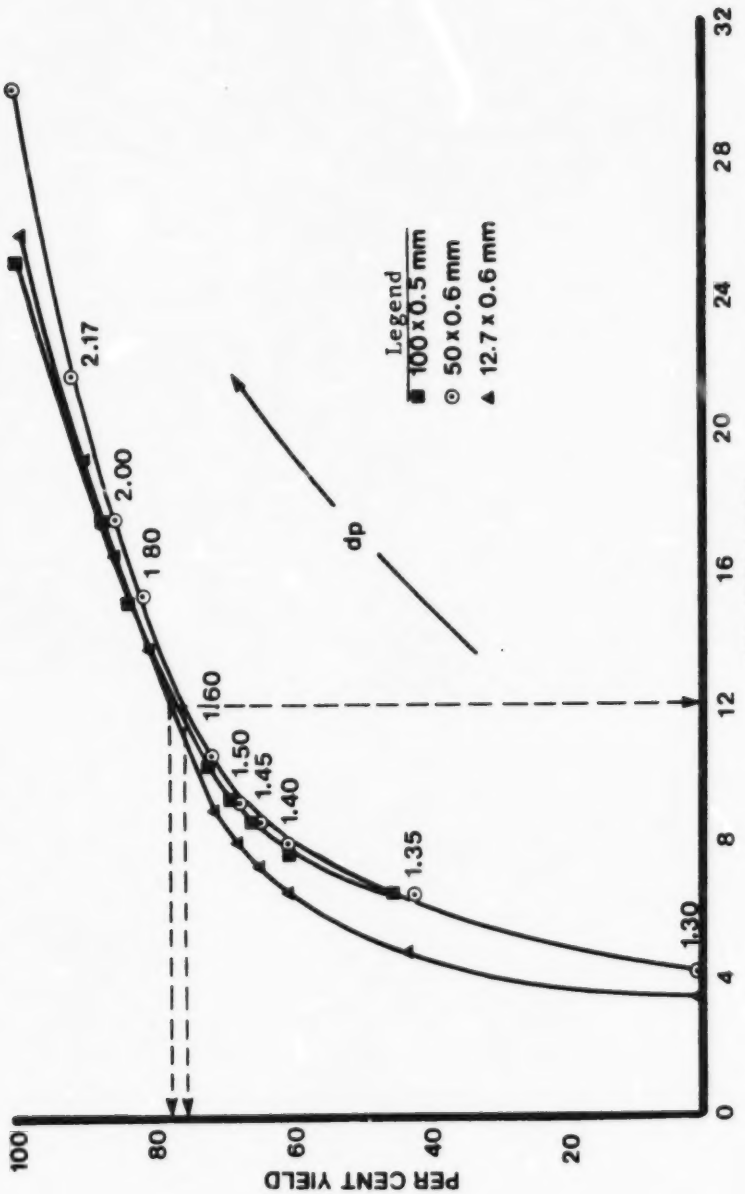


Fig. 5 - Effect of crushing on coal washability.

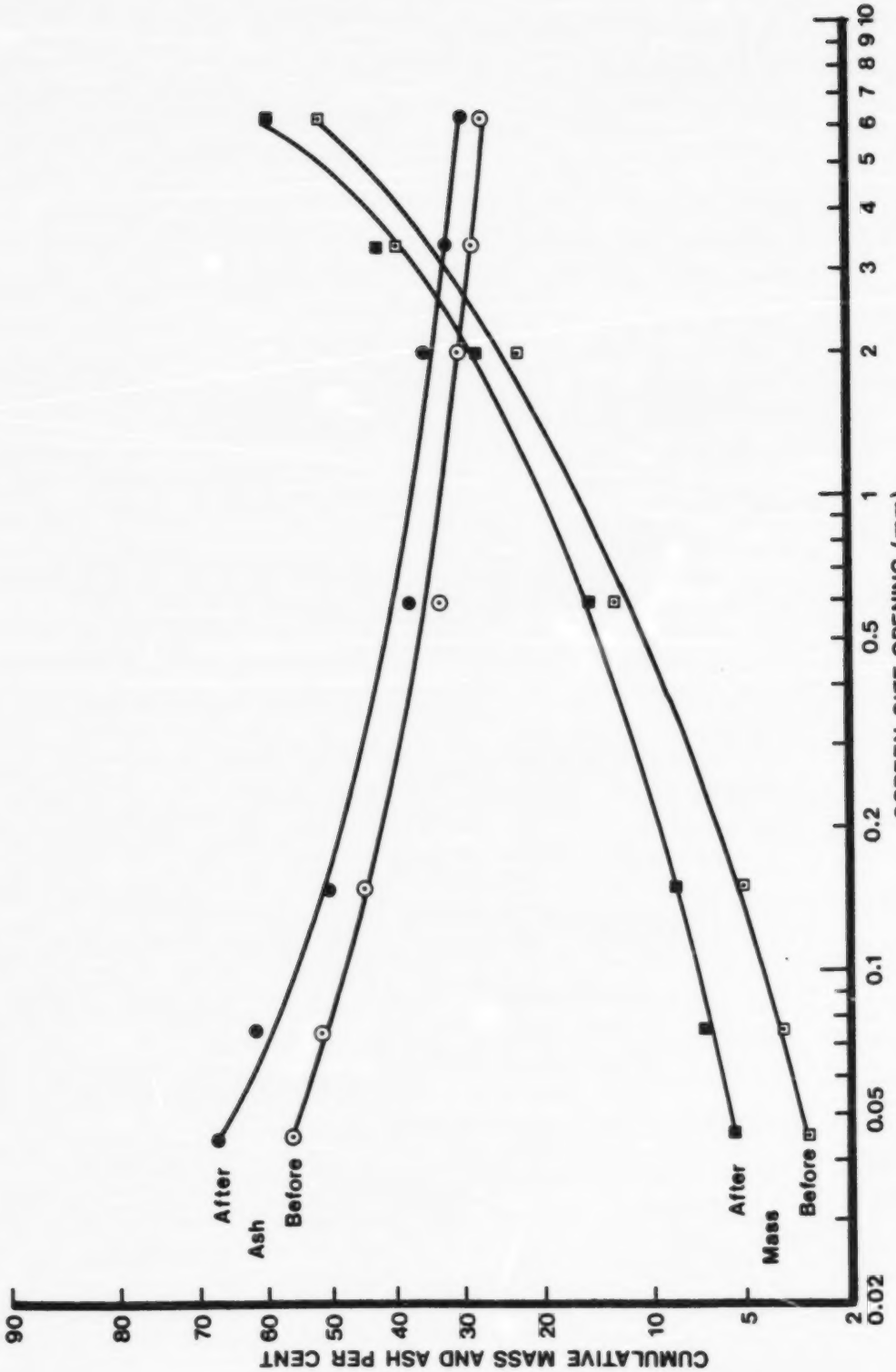
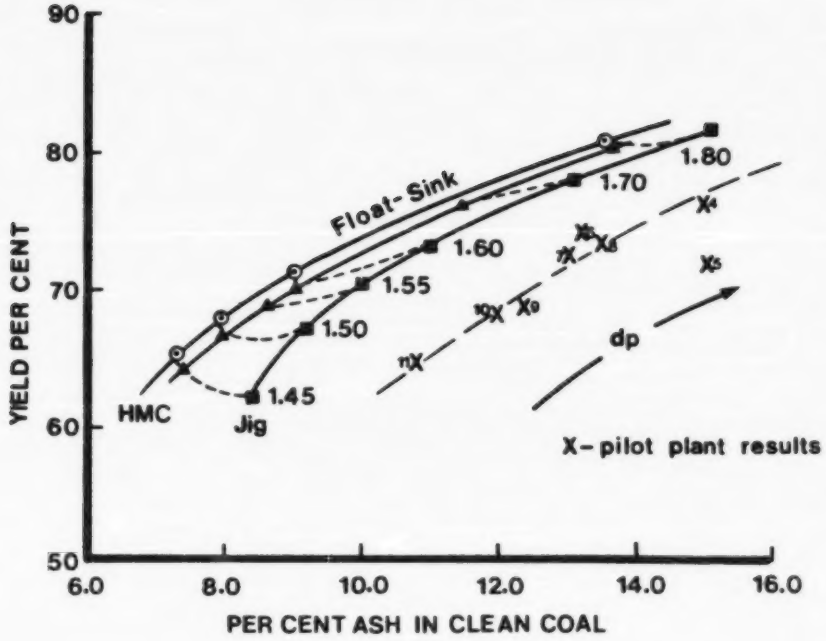


Fig. 6 - Size degradation and per cent ash change during wet attrition test (50 mm x 0)



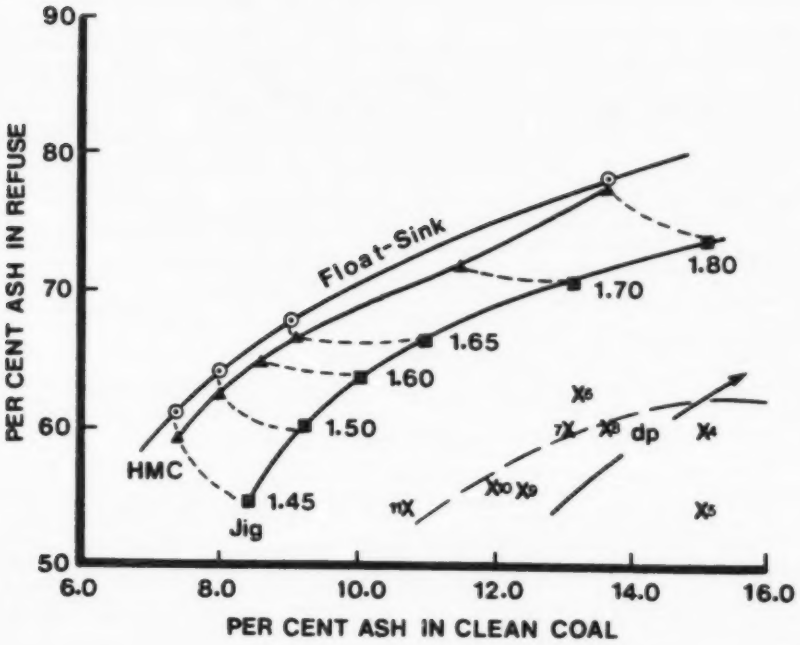


Fig. 7 - Performance evaluation prediction (12 x 0.6mm).

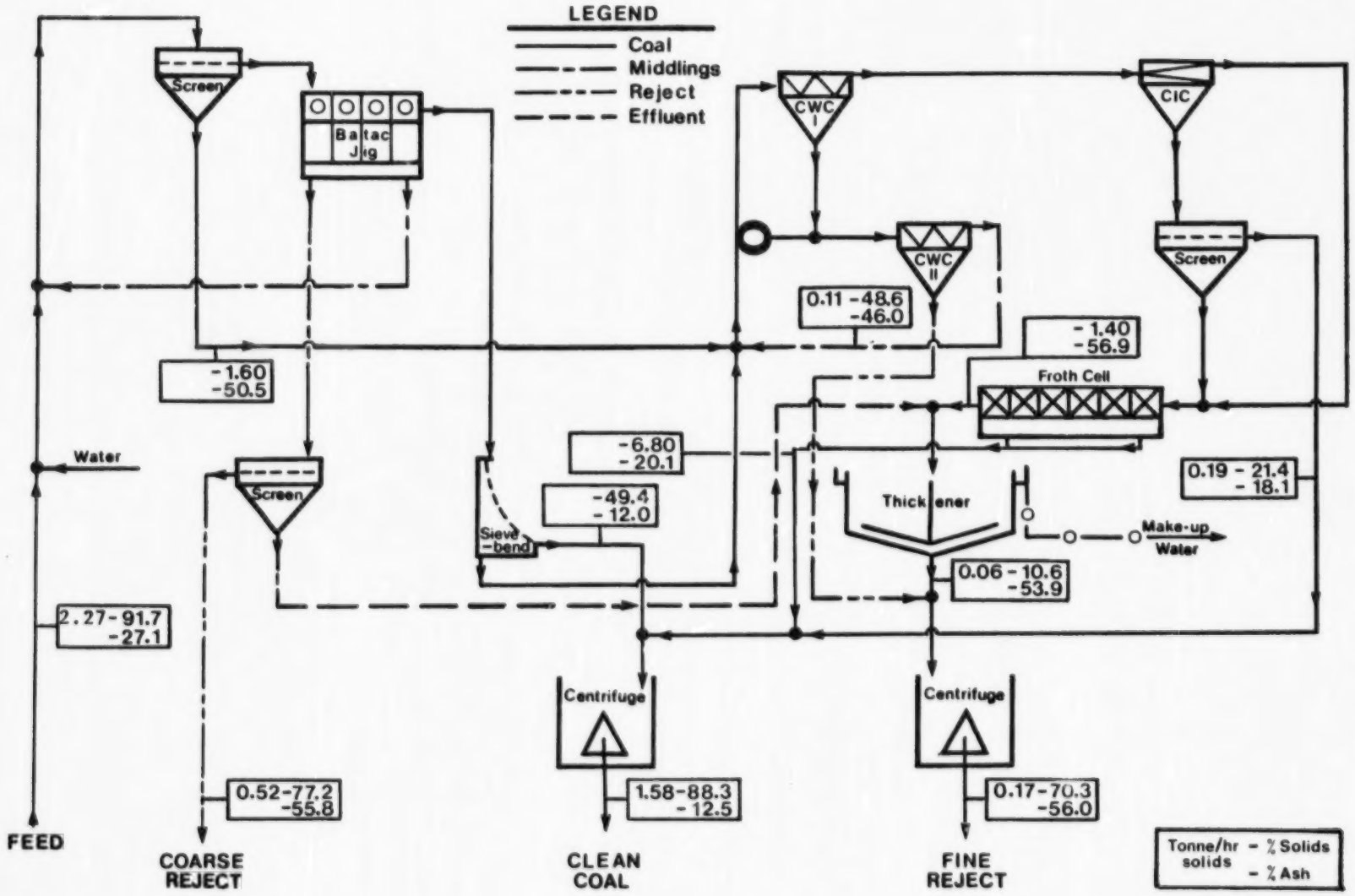


Fig. 8 - Simplified pilot plant flowsheet with partial material balance (test 10).

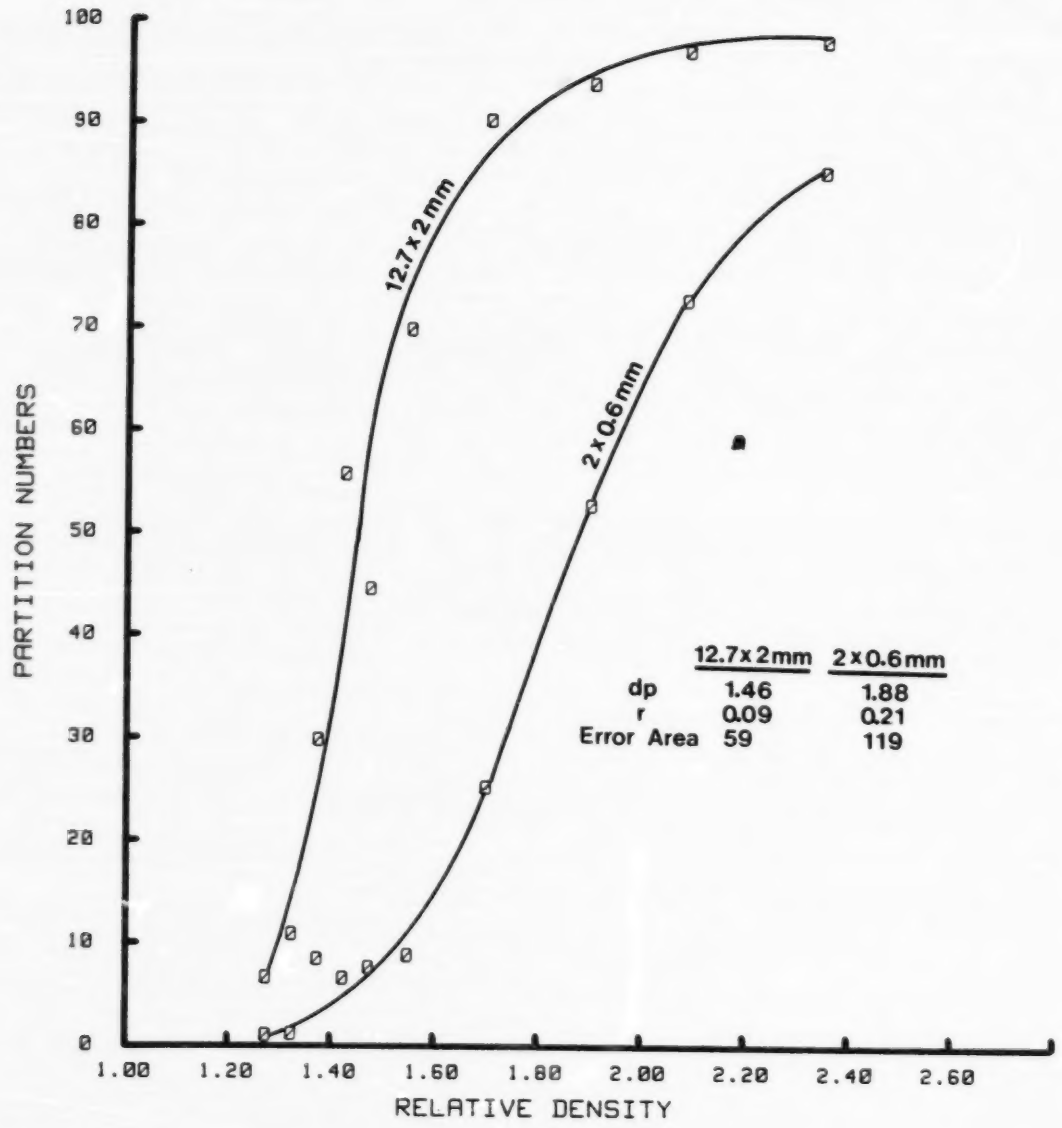


Fig. 9 - Error curves for Batac jig.

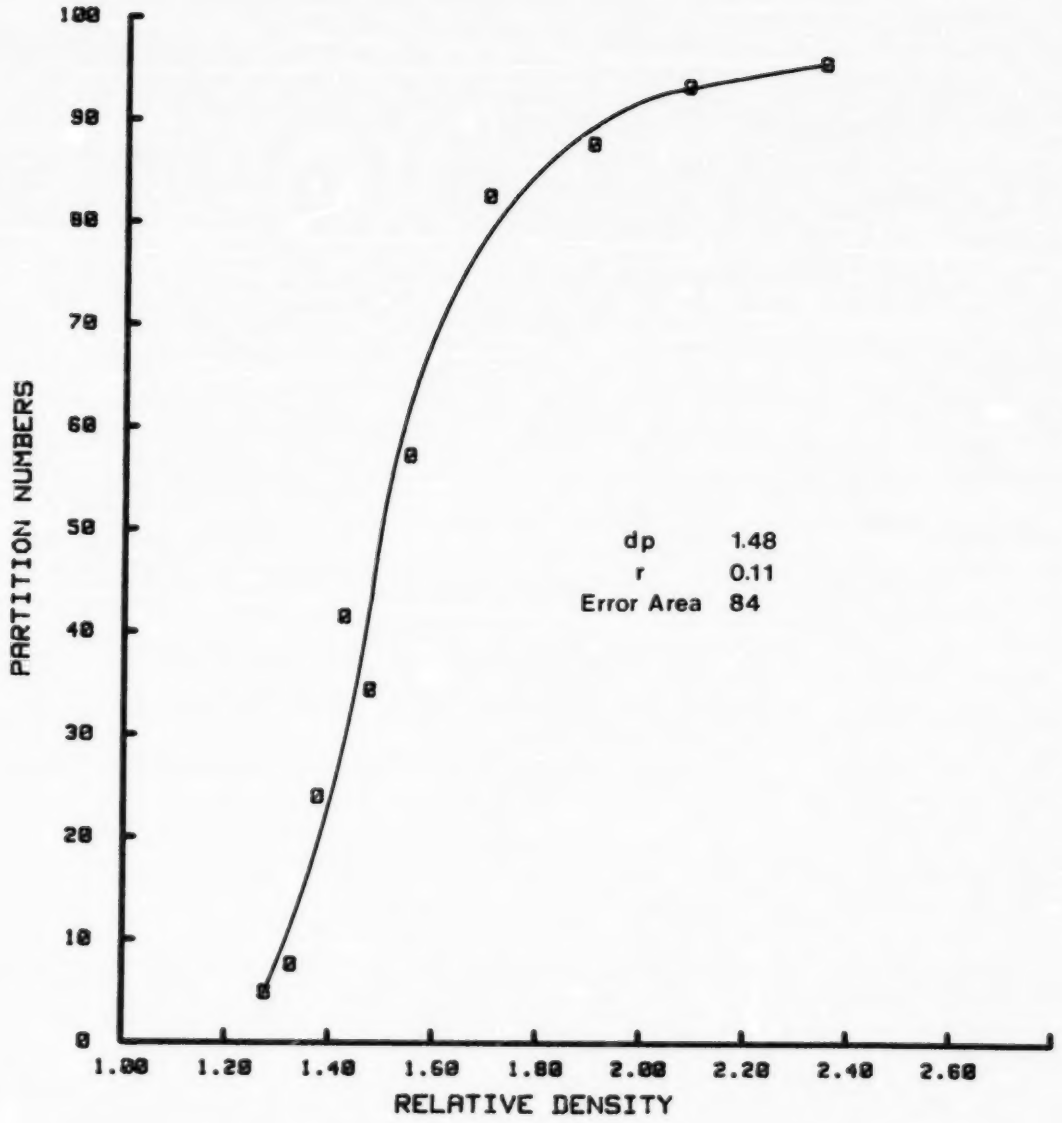


Fig. 10 - Batac jig Error curve for 12 x 0.6 mm.

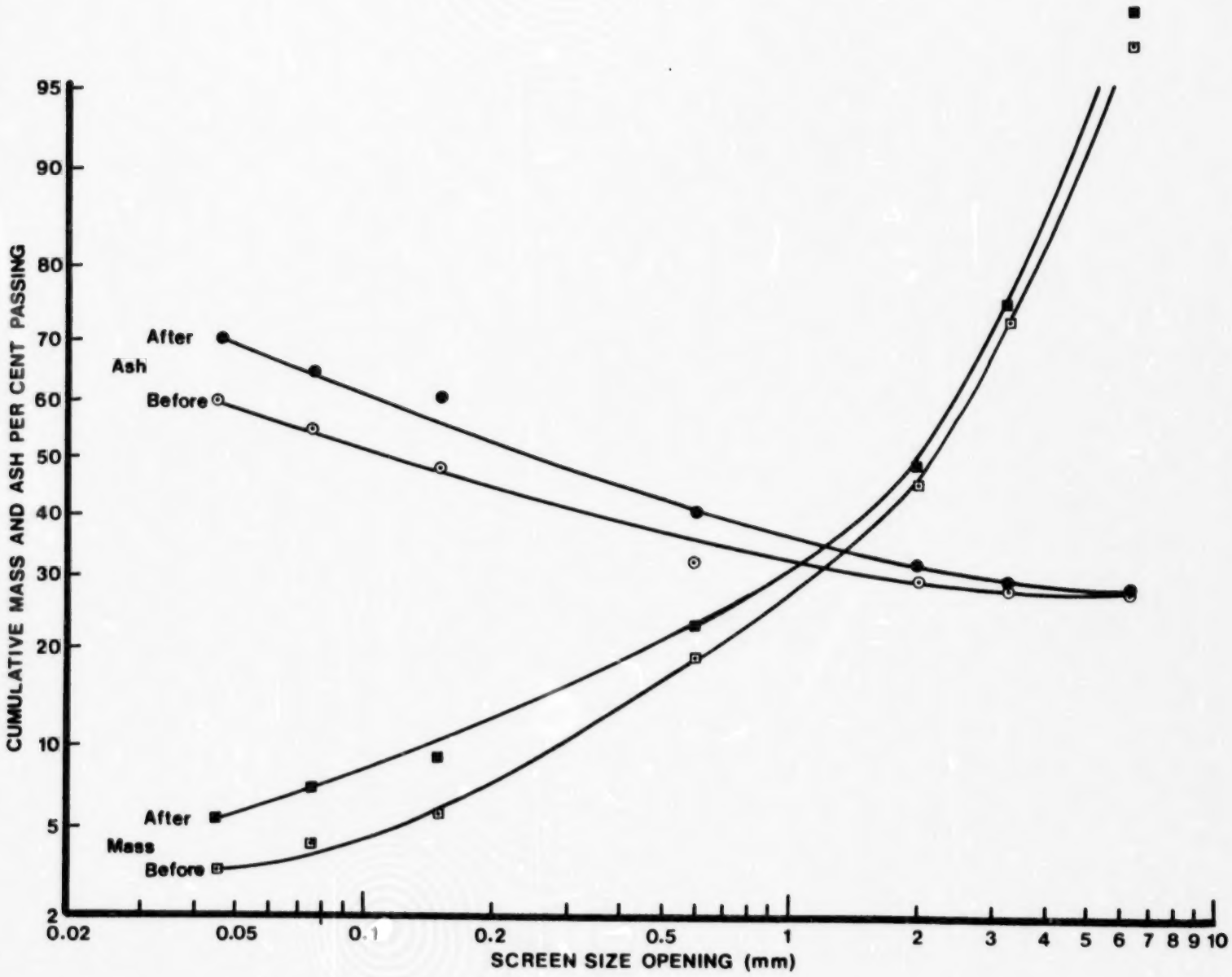


Fig. 11 - Size degradation and per cent ash change during wet attrition test (12mm x 0).

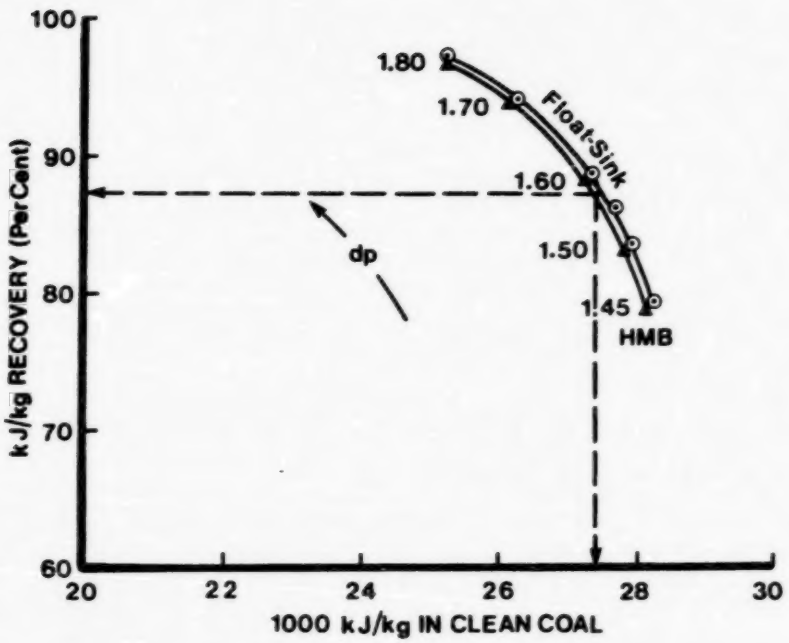


Fig. 12 - Thermal recovery prediction (100 x 12.7mm).

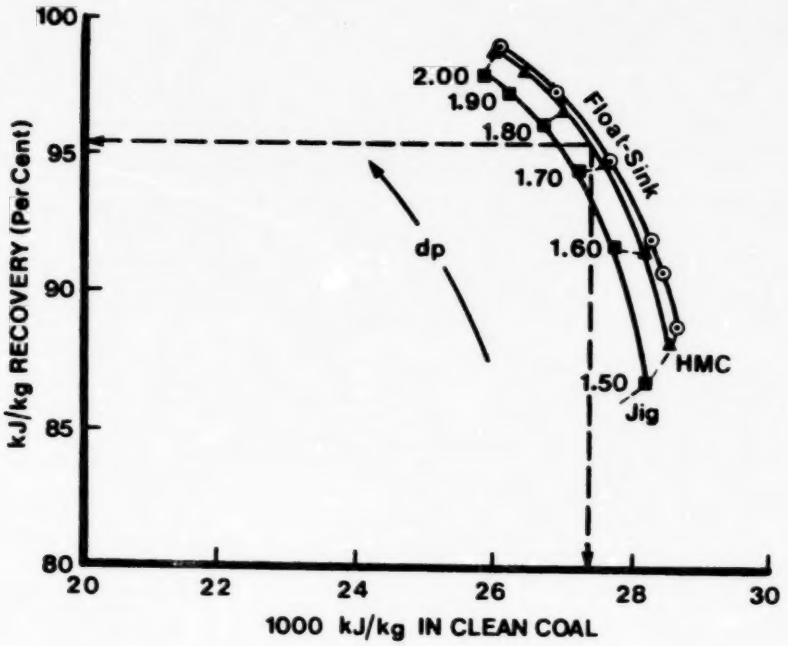


Fig. 13 - Thermal recovery prediction (12.7 x 0.5mm).

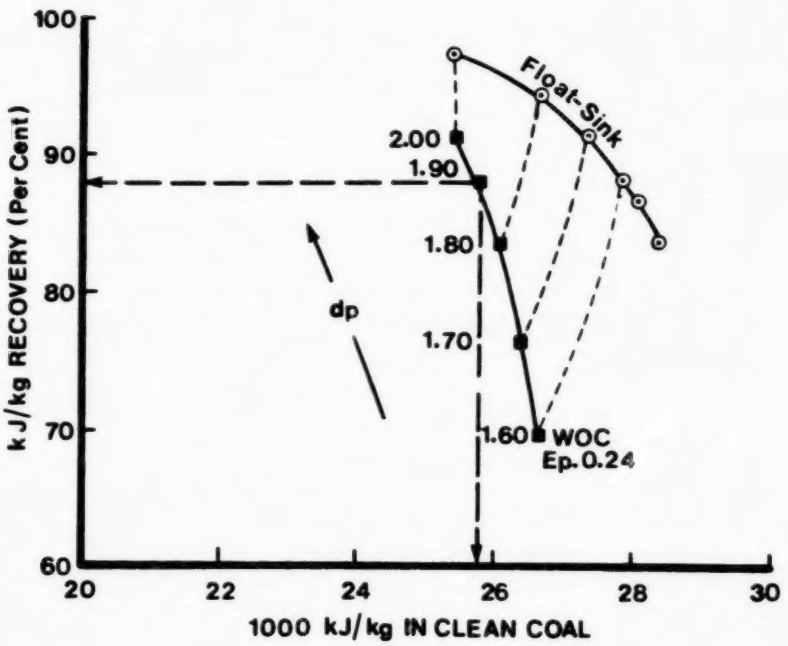


Fig. 14 - Thermal recovery prediction (0.5 x 0.15mm).

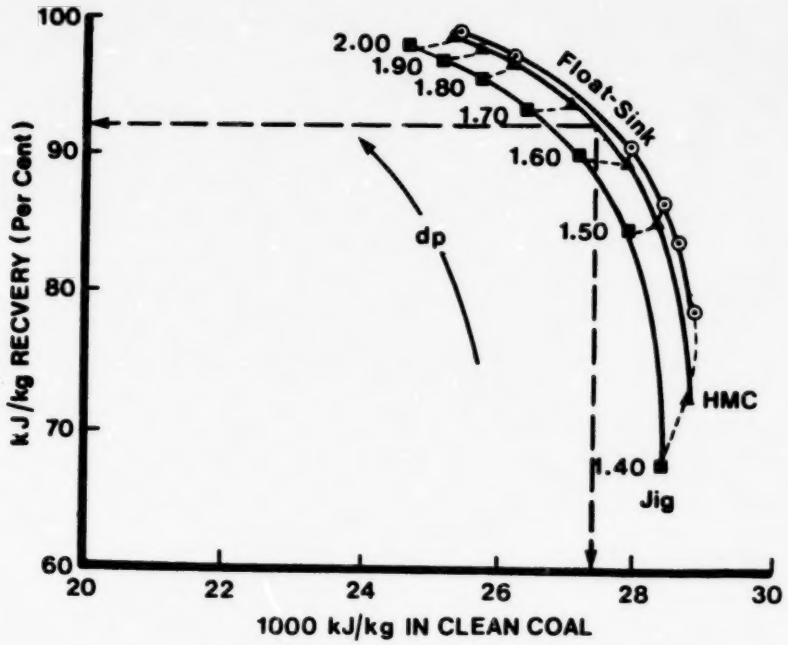


Fig. 15 - Thermal recovery prediction (50 x 0.6mm).

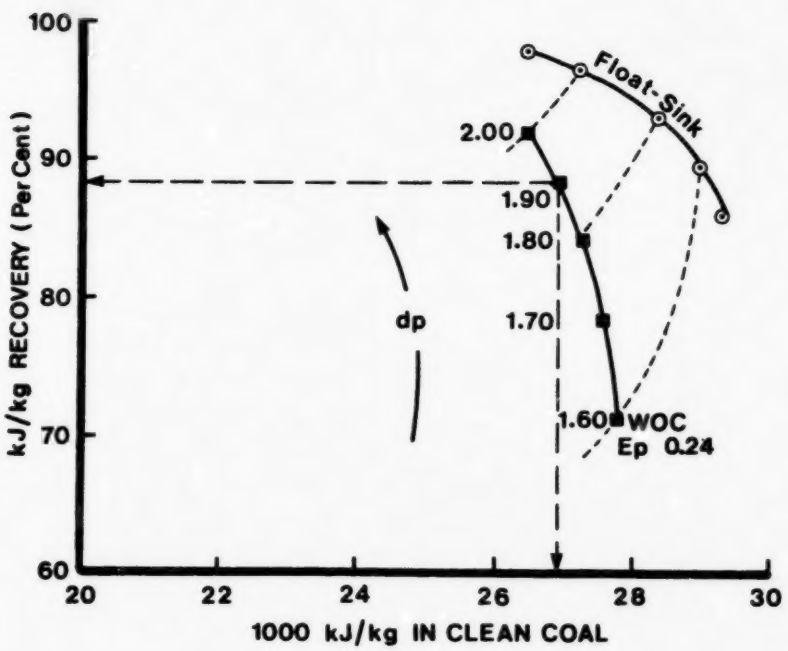


Fig. 16 - Thermal recovery prediction (0.6 x 0.15 mm).

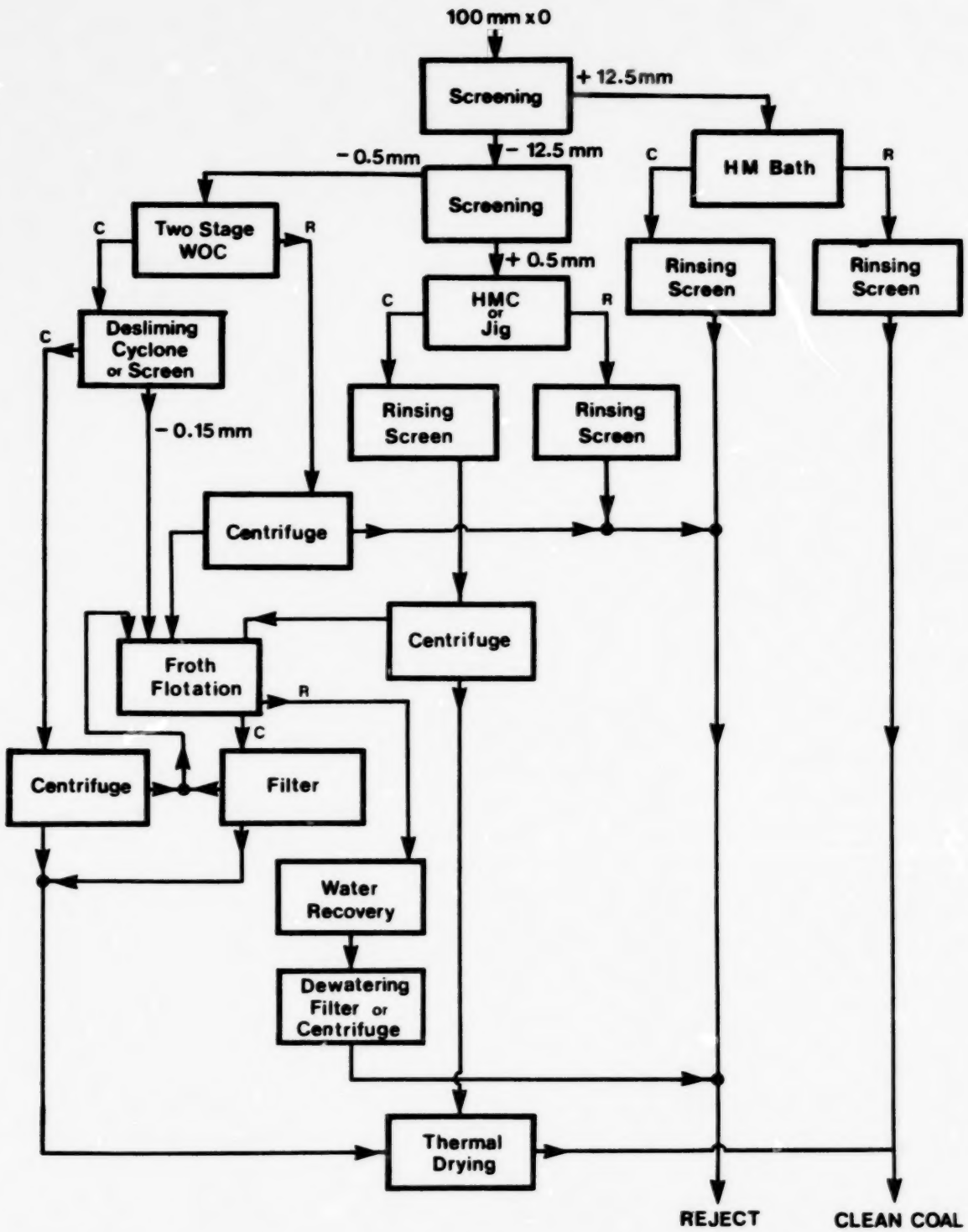


Fig. 17 - Schematic of proposed preparation plant.

APPENDIX A

WASHABILITY DATA AND ASH - kJ RELATIONSHIP

Table A-1 - Washing characteristics of Petro-Canada coal 100 x 12.7 mm (29.7% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	32.05	6.98	29172	32.05	6.98	29172	100.00	29.28	21257
1.30 - 1.35	21.00	11.29	27642	53.05	8.69	28566	67.95	39.80	17523
1.35 - 1.40	6.96	17.26	25523	60.01	9.68	28213	46.95	52.56	12997
1.40 - 1.45	3.84	22.51	23660	63.85	10.45	27940	39.99	58.70	10817
1.45 - 1.50	2.57	27.93	21737	66.42	11.13	27700	36.15	62.54	9453
1.50 - 1.60	2.72	35.84	18929	69.14	12.10	27354	33.58	65.19	8513
1.60 - 1.80	7.20	45.92	15352	76.34	15.29	26222	30.86	67.78	7595
1.80 - 2.00	5.76	54.67	12247	82.10	18.05	25242	23.66	74.43	5234
2.00 - 2.17	4.86	66.22	8148	86.96	20.74	24287	17.90	80.79	2977
2.17 - Sink	13.04	86.22	1050	100.00	29.28	21257	13.04	86.22	1050

Table A-2 - Washing characteristics of Petro-Canada coal 12.7 x 0.5 mm (58.8% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.35	52.16	6.30	29413	52.16	6.30	29413	100.00	23.04	23470
1.35 - 1.40	13.13	11.51	27564	65.29	7.34	29041	47.84	41.30	16990
1.40 - 1.45	5.11	16.98	25623	70.40	8.04	28793	34.71	52.57	12990
1.45 - 1.50	2.77	22.73	23582	73.17	8.60	28596	29.60	58.72	10809
1.50 - 1.55	1.73	28.38	21577	74.90	9.06	28434	26.83	62.43	9490
1.55 - 1.60	1.64	34.84	19284	76.54	9.61	28238	25.10	64.78	8657
1.60 - 1.70	4.01	43.80	16104	80.55	11.31	27634	23.46	66.87	7915
1.70 - 1.80	4.56	53.00	12839	85.11	13.54	26841	19.45	71.63	6226
1.80 - 2.00	4.12	61.29	9897	89.23	15.75	26059	14.89	77.34	4201
2.00 - Sink	10.77	83.48	2022	100.00	23.04	23470	10.77	83.48	2022

Table A-3 - Washing characteristics of Petro-Canada coal 0.5 x 0.15 mm (7.7% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.35	34.86	5.98	29527	34.86	5.98	29527	100.00	25.26	22685
1.35 - 1.40	17.82	9.93	28126	52.68	7.32	29053	65.14	35.58	19023
1.40 - 1.45	9.62	14.88	26368	62.30	8.49	28638	47.32	45.23	15596
1.45 - 1.50	4.65	20.25	24462	66.95	9.30	28348	37.70	52.98	12847
1.50 - 1.55	3.19	26.42	22273	70.14	10.08	28072	33.05	57.59	11213
1.55 - 1.60	2.05	31.58	20441	72.19	10.69	27855	29.86	60.92	10031
1.60 - 1.70	3.81	39.39	17669	76.00	12.13	27344	27.81	63.08	9264
1.70 - 1.80	4.21	48.23	14532	80.21	14.03	26672	24.00	66.84	7929
1.80 - 2.00	6.55	59.62	10490	86.76	17.47	25450	19.79	70.80	6525
2.00 - Sink	13.24	76.32	4563	100.00	25.26	22685	13.24	76.32	4563

Table A-4 - Washing characteristics of Petro-Canada coal (top size 50 mm) 50 x 25.4 mm (11.2% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
1.30 - 1.35	28.44	7.19	29097	28.44	7.19	29097	100.00	32.10	20256
1.35 - 1.40	20.91	11.51	27564	49.35	9.02	28448	71.56	42.00	16742
1.40 - 1.45	6.16	17.23	25534	55.51	9.93	28124	50.65	54.59	12274
1.45 - 1.50	3.29	21.58	23990	58.80	10.58	27893	44.49	59.77	10438
1.50 - 1.60	7.48	28.98	21364	66.28	12.66	27156	41.20	62.81	9356
1.60 - 1.80	13.31	51.64	13322	79.59	19.18	24843	33.72	70.32	6692
1.80 - 2.00	2.94	64.77	8662	82.53	20.80	24266	20.41	82.50	2369
2.00 - 2.17	12.13	84.23	1756	94.66	28.93	21382	17.47	85.49	1310
2.17 - Sink	5.34	88.34	297	100.00	32.10	20256	5.34	88.34	297

Table A-5 - Washing characteristics of Petro-Canada coal 25.4 x 12.7 mm (27.09% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.10	5.40	29733	0.10	5.40	29733	100.00	27.73	21809
1.30 - 1.35	41.23	7.60	28952	41.33	7.59	28954	99.90	27.75	21801
1.35 - 1.40	17.99	12.22	27312	59.32	9.00	28456	58.67	41.91	16776
1.40 - 1.45	3.46	19.88	24594	62.78	9.60	28243	40.68	55.03	12117
1.45 - 1.50	2.86	23.11	23447	65.64	10.19	28034	37.22	58.30	10957
1.50 - 1.60	5.85	31.89	20331	71.49	11.96	27404	34.36	61.23	9918
1.60 - 1.80	12.30	49.84	13961	83.79	17.52	25430	28.51	67.25	7781
1.80 - 2.00	3.81	64.65	8705	87.60	19.57	24703	16.21	80.46	3092
2.00 - 2.17	7.78	83.23	2111	95.38	24.76	22860	12.40	85.32	1368
2.17 - Sink	4.62	88.85	116	100.00	27.73	21809	4.62	88.85	116

Table A-6 - Washing characteristics of Petro-Canada coal 12.7 x 2 mm (46.55% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	1.30	4.08	30201	1.30	4.08	30201	100.00	25.03	22765
1.30 - 1.35	45.26	6.34	29399	46.56	6.28	29421	98.70	25.31	22667
1.35 - 1.40	17.86	11.45	27585	64.42	7.71	28912	53.44	41.38	16965
1.40 - 1.45	3.92	17.71	25364	68.34	8.28	28709	35.58	56.40	11634
1.45 - 1.50	2.51	23.05	23469	70.85	8.81	28523	31.66	61.19	9934
1.50 - 1.60	3.11	30.87	20693	73.96	9.74	28194	29.15	64.47	8768
1.60 - 1.80	9.14	48.79	14333	83.10	14.03	26669	26.04	68.48	7344
1.80 - 2.00	4.02	61.78	9723	87.12	16.23	25887	16.90	79.13	3564
2.00 - 2.17	3.82	80.26	3165	90.94	18.92	24933	12.88	84.55	1642
2.17 - Sink	9.06	86.36	1000	100.00	25.03	22765	9.06	86.36	1000

Table A-7 - Washing characteristics of Petro-Canada coal 2 x 0.6 mm (13.20% of total).

Relative Density Fractions	Elementary data			Cumulative data					
				Float			Sink		
	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg	Mass %	Ash %	kJ/kg
Float- 1.30	0.90	3.89	30268	0.90	3.89	30268	100.00	29.66	21124
1.30 - 1.35	38.55	5.95	29537	39.45	5.90	29554	99.10	29.89	21041
1.35 - 1.40	16.54	11.11	27706	55.99	7.44	29008	60.55	45.13	15632
1.40 - 1.45	4.71	15.86	26020	60.70	8.09	28776	44.01	57.92	11094
1.45 - 1.50	2.92	21.69	23951	63.62	8.72	28555	39.30	62.96	9305
1.50 - 1.60	3.52	30.20	20931	67.14	9.84	28155	36.38	66.27	8129
1.60 - 1.80	7.91	45.39	15540	75.05	13.59	26826	32.86	70.14	6759
1.80 - 2.00	5.39	60.78	10078	80.44	16.75	25703	24.95	77.98	3974
2.00 - 2.17	6.42	79.16	3555	86.86	21.37	24066	19.56	82.72	2292
2.17 - Sink	13.14	84.46	1674	100.00	29.66	21124	13.14	84.46	1674

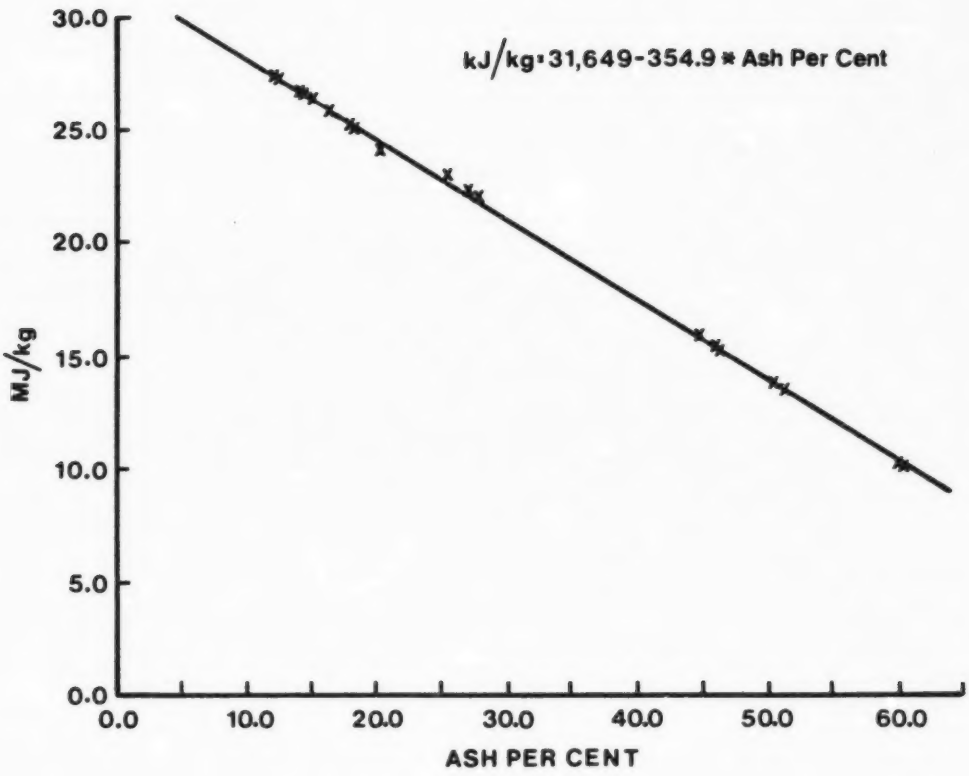


Fig. A-1 - Ash - kJ relationship of Kipp mine coal (composite sample).